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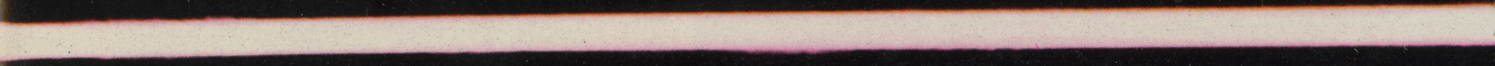

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Laser: The New Light

Three scientists at Bell Telephone Laboratories were experimenting in a darkened room with a long glass tube that glowed like a pink neon sign. Surrounding it was an assortment of mirrors, lenses and electronic equipment.

The physicists stopped to relax at 4:15 p.m. on this Tuesday, December 13, 1960. To the three weary men it seemed another day of failure. Little did they suspect that success lay within the flick of a finger.

For many months, they had theorized, planned and experimented. Their aim: to produce a calculated behavior among the molecules of two gases sealed inside the 40-inch length of tube. If successful, out of one end of the tube would stream forth a new kind of light — supremely pure light, beaming continuously with extraordinary intensity!

If they could make this happen, they would create a new and special member of the family of devices called *masers.* This latter device would be a light-producing maser, or *laser.* (Pronounced MAY-zer and LAY-zer.)

They had built upon concepts advanced by men like Niels Bohr, Albert Einstein, and Charles H. Townes. Ali Javan had conceived of the two-gas laser and with the other two Bell Labs physicists — Donald R. Herriott, and William R. Bennett, Jr. — had worked out the theory and design. They expected their device to "lase" smoothly, continuously — unlike previous lasers which fired in very short bursts of light.

But so far they hadn't made it work at all. Several experimental models had been built, but these failed to lase. Now the three men had incorporated all they had learned into a new, very carefully constructed model. But trouble continued to plague them. Thin mirror coatings had cracked. Several times the men had pumped the gases out of the tube and refilled it. And now — still it failed to lase.

The men left the tube energized as they relaxed and discussed what they should do next. But Don Herriott continued to fiddle with the adjustment knob on a mirror. Then — suddenly he noticed the long-sought "peak" on the oscilloscope indicating laser action! The men were ecstatic. All that had been needed was that slight turning of the mirror. Overcoming an initial fear of disturbing and disrupting the invisible infrared beam, they very carefully adjusted the laser to maximum efficiency.

Word of their success traveled, it seemed, almost as fast as the light itself. Colleagues trooped in to witness what no one, anywhere, had ever seen before. The evening was one of quiet jubilation among Bell Labs scientists.

The next day Herriott and Bennett noticed that when they spoke near the delicately adjusted mirrors the vibrations produced by their voices caused variations in the laser's output. They attached an earphone to the laser output oscilloscope. The earphone reproduced their voices — they were talking over the laser.

It happened that Javan had gone to New York for the day. When he called the laboratories in New Jersey on the telephone, Herriott and Bennett held the earphone near the telephone mouthpiece and took turns talking to Javan over the laser. They shouted at the mirror — and thence by telephone to Javan — the historic words of Alexander Graham Bell, "Mr. Watson, come here, I want you!" . . . Thus scientists celebrated the first continuous laser.

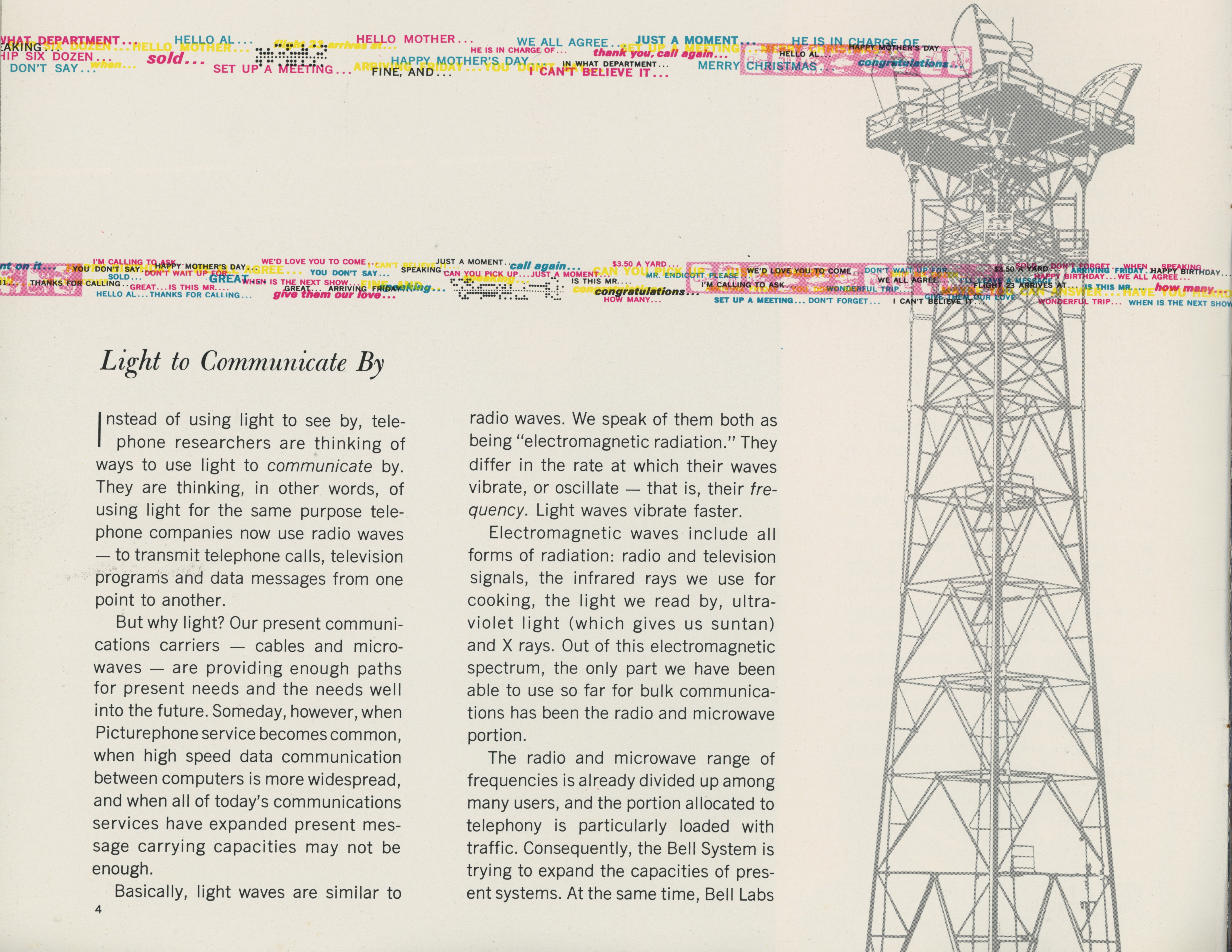
Facing page: Two scientists check correctness of the alignment of laser tubes containing the noble gases—helium, neon, argon, krypton, and xenon.

Ali Javan, William R. Bennett, Jr., and Donald R. Herriott adjust the helium-neon laser.

A host of scientists and engineers in many organizations have contributed laser concepts and developments. And they have produced laser action in an array of materials. Researchers have performed experiments with beams of laser light which, taken singly, are startling; taken collectively, they suggest that the laser may be one of the most important scientific and technological advances of the Twentieth Century. Lasers have been used in experiments to:

— Provide an extremely accurate "yardstick."
— Weld detached retinas inside the human eye, without surgery.
— Bounce light off the moon.
— Confirm Einstein's theory of relativity.
— Burn holes through metal and vaporize diamonds.

Such experiments have little to do with telephone service. Just what is the Bell System's interest in the laser? And why has Bell Labs played such a large part in the pioneering and the development of lasers? The answer is that Bell Telephone Laboratories scientists not only are using the laser's new light as a tool for scientific research, but are investigating another possible use for laser light which is fundamental to telephone service. If technically and economically sound, the laser might someday prove as beneficial to communications as a notable Bell Labs invention of 1947 — the transistor.


WHAT DEPARTMENT...
HELLO AL...
flight 23 arrives at...
HELLO MOTHER...
WE ALL AGREE...
JUST A MOMENT...
HE IS IN CHARGE OF
SPEAKING...
SIX DOZEN...
HELLO MOTHER...
HE IS IN CHARGE OF...
thank you, call again...
SET UP A MEETING...
MERRY CHRISTMAS...
HAPPY MOTHER'S DAY...
SHIP SIX DOZEN...
sold...
HAPPY MOTHER'S DAY...
HELLO AL...
DON'T SAY...
when...
SET UP A MEETING...
ARRIVING FRIDAY...
FINE, AND...
YOU DON'T SAY...
IN WHAT DEPARTMENT...
I CAN'T BELIEVE IT...
MERRY CHRISTMAS...
congratulations...
I'M CALLING TO ASK
YOU DON'T SAY...
HAPPY MOTHER'S DAY...
WE ALL AGREE...
SOLD...
DON'T WAIT UP FOR...
GREAT...
THANKS FOR CALLING...
GREAT... IS THIS MR....
HELLO AL... THANKS FOR CALLING...
WE'D LOVE YOU TO COME...
YOU DON'T SAY...
WHEN IS THE NEXT SHOW...
GREAT... ARRIVING FRIDAY...
give them our love...
I CAN'T BELIEVE IT...
JUST A MOMENT...
SPEAKING
FINE, AND...
speaking...
CAN YOU PICK UP... JUST A MOMENT...
call again...
IS THIS MR....
$3.50 A YARD...
CAN YOU PICK UP...
MR. ENDICOTT PLEASE...
congratulations...
HOW MANY...
WE'D LOVE YOU TO COME...
I'M CALLING TO ASK...
ARRIVING FRIDAY...
SET UP A MEETING... DON'T FORGET...
DON'T WAIT UP FOR...
WE ALL AGREE...
WONDERFUL TRIP...
I CAN'T BELIEVE IT...
I'LL LEAVE A MESSAGE
GIVE THEM OUR LOVE
FLIGHT 23 ARRIVES AT...
MAYBE YOU CAN ANSWER...
$3.50 A YARD
SOLD
DON'T FORGET...
WHEN...
SPEAKING
ARRIVING FRIDAY...
HAPPY BIRTHDAY...
HAPPY BIRTHDAY... WE ALL AGREE...
IS THIS MR....
how many...
HAVE YOU HEARD
WONDERFUL TRIP...
WHEN IS THE NEXT SHOW

Light to Communicate By

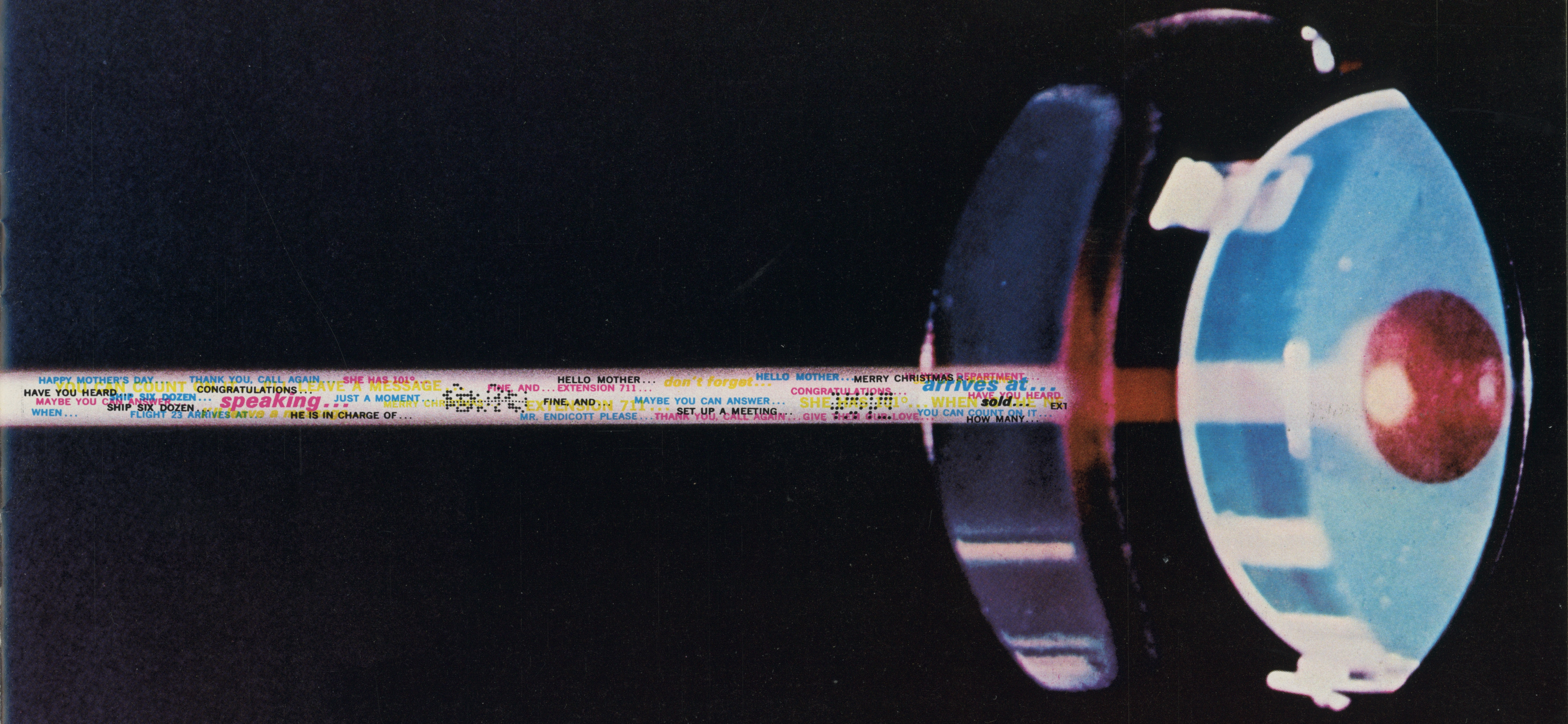
Instead of using light to see by, telephone researchers are thinking of ways to use light to *communicate* by. They are thinking, in other words, of using light for the same purpose telephone companies now use radio waves — to transmit telephone calls, television programs and data messages from one point to another.

But why light? Our present communications carriers — cables and microwaves — are providing enough paths for present needs and the needs well into the future. Someday, however, when Picturephone service becomes common, when high speed data communication between computers is more widespread, and when all of today's communications services have expanded present message carrying capacities may not be enough.

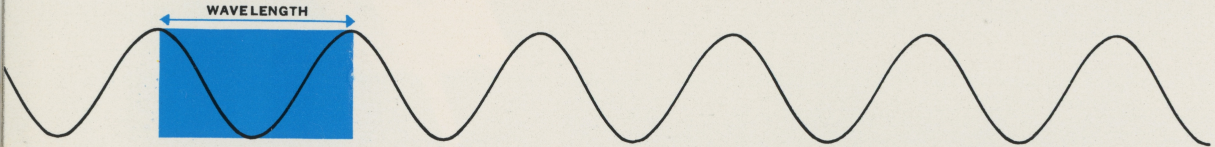
Basically, light waves are similar to radio waves. We speak of them both as being "electromagnetic radiation." They differ in the rate at which their waves vibrate, or oscillate — that is, their *frequency.* Light waves vibrate faster.

Electromagnetic waves include all forms of radiation: radio and television signals, the infrared rays we use for cooking, the light we read by, ultraviolet light (which gives us suntan) and X rays. Out of this electromagnetic spectrum, the only part we have been able to use so far for bulk communications has been the radio and microwave portion.

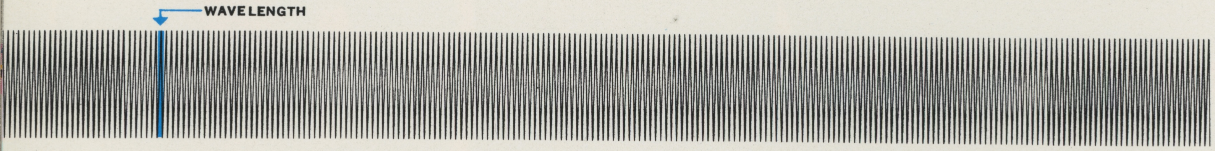
The radio and microwave range of frequencies is already divided up among many users, and the portion allocated to telephony is particularly loaded with traffic. Consequently, the Bell System is trying to expand the capacities of present systems. At the same time, Bell Labs


HAPPY MOTHER'S DAY...
THANK YOU, CALL AGAIN...
SHE HAS 101°...
YOU CAN COUNT ON IT...
LEAVE A MESSAGE...
HAVE YOU HEARD...
CONGRATULATIONS...
SHIP SIX DOZEN...
MAYBE YOU CAN ANSWER...
speaking...
JUST A MOMENT...
MERRY CHRISTMAS
SHIP SIX DOZEN...
WHEN...
FLIGHT 23 ARRIVES AT...
HE IS IN CHARGE OF...
FINE, AND...
EXTENSION 711...
HELLO MOTHER...
don't forget...
FINE, AND...
EXTENSION 711...
MAYBE YOU CAN ANSWER...
SET UP A MEETING...
MR. ENDICOTT PLEASE...
THANK YOU, CALL AGAIN...
HELLO MOTHER...
MERRY CHRISTMAS
CONGRATULATIONS...
SHE HAS 101°...
WHEN
GIVE THEM OUR LOVE...
DEPARTMENT...
arrives at...
HAVE YOU HEARD
sold...
YOU CAN COUNT ON IT...
HOW MANY...
EXT

ELECTROMAGNETIC RADIATION is pictured as a train of waves. Whether the radiation is radio, visible light, or X ray, it travels at the same velocity (186,000 miles per second in a vacuum). The kinds of radiation differ in the distance between wave crests (wavelength), and the number of vibrations per second (frequency). A complete vibration encompasses one wavelength. The behavior of two different waves can be compared to two men running a race in exactly the same time (velocity). One man has a long-legged stride, the other, a short-legged stride (wavelength). To keep up with the long-legged man, the short one must take many more steps (frequency).



This microwave has a wavelength of about one inch and a frequency of about 10 billion cycles per second.



Imagine a wavelength about 1,000 times shorter than the one you see here and you will have a wave in the red range of visible light with a frequency of about 430 trillion cycles per second.

scientists are exploring the possibility of opening up the "unused" portion of the spectrum — the infrared, visible light, and the ultraviolet regions.

The regions beyond microwaves not only are unused, but are potentially far more fertile for communications. A rule of thumb in communications science says that as you increase the frequency of electromagnetic radiation, you increase its information-handling capacity. As you move up the spectrum from low frequency waves used for radio broadcasting, through and beyond the microwaves that carry thousands of telephone calls and TV, you get more capacity — more waves onto which you can pack messages.

Light waves oscillate from a thousand to a million times faster than microwave radio waves. In addition, the light spectrum is very broad. In just the small portion of it that is visible to people, there is about a million times more room for messages than there is in the entire range of frequencies we now use for communications. This advantage is marred, however, by several big "ifs": If scientists and engineers can find ways to control and manipulate these light waves economically; if they can find a way to prevent conditions such as dust, fog, and rain from obscuring the light beam; if the need really does occur for the large capacities of lasers; and if lasers can compete economically with other systems that are continually improving and expanding their capacities.

Nevertheless, the goal of practical communication by laser light is worth seeking so that eventually, if the need arises, we may be able to respond.

THE COMPOSITION OF THE ELECTROMAGNETIC SPECTRUM

COSMIC RAYS are tremendously high energy radiation from outer space. Colliding with atoms in the earth's atmosphere, they create all manner of atomic particles. The nuclear physicist duplicates some of these reactions in particle accelerators or "atom smashers" and studies them in an attempt to probe the composition of matter.

GAMMA RAYS are radiation with very high penetrating power. They are emitted by the naturally radioactive elements such as radium, and as a by-product of a nuclear reaction. An overdose of this radiation is deadly, but medical science uses it as a weapon against cancers, tumors, and lesions. The behavior of gamma rays is studied by the physicist in high speed accelerators.

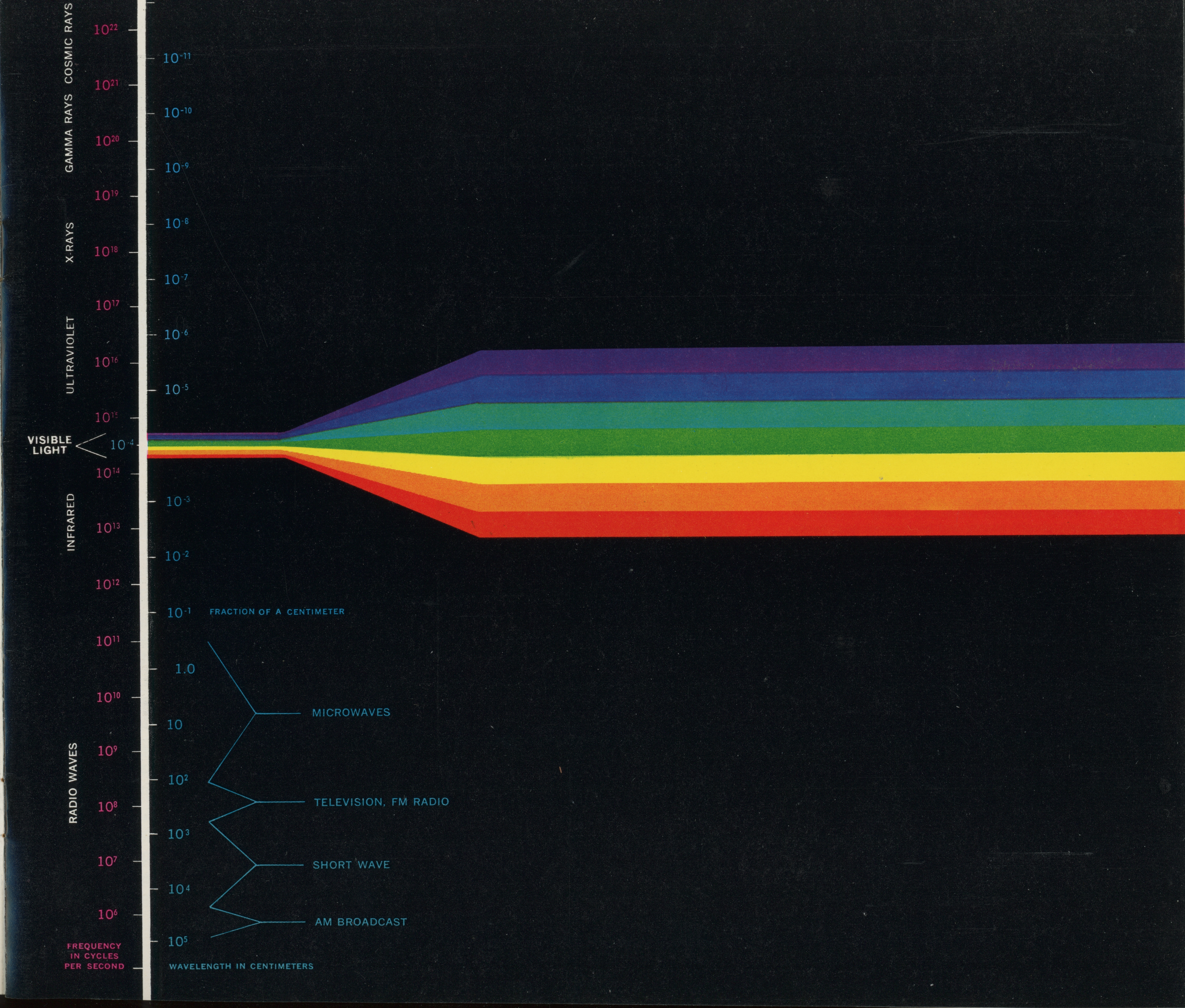
X RAYS penetrate ordinarily opaque materials, but to a lesser degree than gamma rays. The X-ray photograph is used in medical diagnosis and the ray itself can kill cancer cells. To create X rays, a stream of high-speed electrons bombards a metal plate in a vacuum, disturbing the electron structure of atoms in the plate. Energy, in the form of X-ray radiation is given off from the plate.

ULTRAVIOLET RADIATION is invisible. Most ultraviolet radiation from the sun is absorbed in the atmosphere. Nevertheless, it is quite important to health, producing vitamin D by its action on substances in the skin and plants. The commonly used artificial source is the mercury arc.

THE NATURE OF VISIBLE LIGHT RADIATION has been the special concern of scientists since ancient times. Isaac Newton, in 1672, discovered that a beam of white light passed through a triangular, transparent prism, bends from its original direction and is dispersed in sequence. Scientists speculated that light was propagated as a wave; discovered its speed; evolved the electromagnetic wave theory unifying visible and invisible radiation; and delved deep in atomic structure to explain the sources of radiation and its behavior. Having identified the sources of specific radiation, scientists wanted to put some of it to work. Discovery of the LASER principle enabled the scientist to select a tiny bit of radiation from the visible range and amplify it into a powerful tool.

INFRARED RADIATION is invisible. Atmospheric haze freely transmits it. Photographic film made sensitive to infrared radiation reveals objects hidden by darkness or haze. Infrared is widely used for many heating requirements. The common source is a specially engineered incandescent lamp. Certain lasers operate in the infrared range.

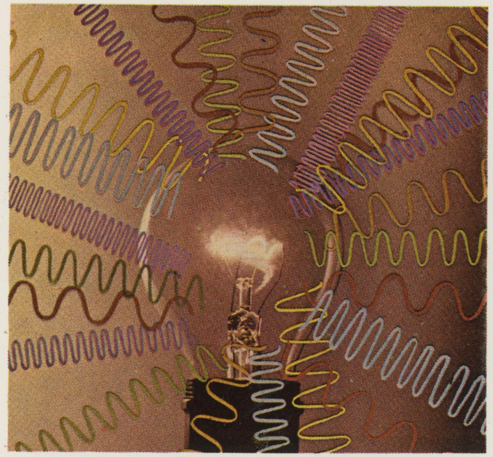
RADIO WAVES cover a broad band of the spectrum from several millimeters to 5 or 6-mile wavelengths. Frequencies range from about 30,000 to 10 billion cycles per second. Practical use of these waves developed rapidly after they were theorized by James Maxwell in 1869, and proved by Heinrich Hertz in 1887. Marconi transmitted wireless signals in 1896. Reginald Fessenden transmitted voice on a crude apparatus in 1900. Dr. Lee De Forest's three-element vacuum tube in 1907 ushered in the era of wireless communication by providing an efficient, economical generator and amplifier of radio waves. The LASER principle is the first basic departure in wave amplification since De Forest's invention.


COSMIC RAYS
GAMMA RAYS
X-RAYS
ULTRAVIOLET
VISIBLE LIGHT
INFRARED
RADIO WAVES
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
FREQUENCY IN CYCLES PER SECOND
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
FRACTION OF A CENTIMETER
1.0
10
10^{2}
10^{3}
10^{4}
10^{5}
WAVELENGTH IN CENTIMETERS
MICROWAVES
TELEVISION, FM RADIO
SHORT WAVE
AM BROADCAST

"Coherent" Light

LASER LIGHT IS COHERENT — all random radiation is eliminated from the system and only a single frequency with all the waves in step is emitted.

IN AN ELECTRIC LIGHT, the atoms and electrons in the filament material are heated with an electric current, absorb energy and become excited. As the excited atoms "relax," in a random fashion, they radiate light that is random in direction and frequency. It is *incoherent.*



The notion of using light for voice communication isn't new. As far back as 1880 — only four years after the telephone was invented—Alexander Graham Bell set up an experiment that demonstrated the feasibility of transmitting a voice by light waves, but only for a distance of several hundred feet.

Light beams have long been used to imprint the sound track on movie film and then to convert the track back into sound. And, of course, light has been used in blinker and signal systems for hundreds of years. But these systems do not begin to approach the theoretical message-carrying capacity of light — if it's in the proper form.

Ordinary light sources radiate light that is *incoherent.* This means just what you might expect — a jumble, or mixture. Light from a bulb contains all the colors of the spectrum. Each color radiates energy at a different frequency. Stated in terms of electromagnetic en-

ergy, it contains a jumble of frequencies. Many frequencies are emitted in random directions at random times. The light isn't suitable for carrying very much information — just a few voice channels.

But *coherent* light is different. It is a single frequency. All the waves move in step like a regiment of soldiers. And all are parallel, in a narrow beam. No one had ever produced such a light until the laser came along. The exciting fact which stirs the imagination of communications scientists is that, unlike incoherent light, laser light *does* have the theoretical capacity of transmitting huge amounts of information. Voice, data and TV programs might be carried in enormously greater numbers than can be carried by present-day radio waves.

Necessity Foreseen— The Mother of Invention

Communication at radio and microwave frequencies is possible because electron tubes and transistors are available to generate and amplify vibration in those frequencies. An electron tube, for example, can take the TV signal that reaches your home antenna and build it up or, more properly, amplify it. If you feed an amplified stream of electrons back into a tube again, the energy goes around and around and you have an *oscillator,* a device that generates electromagnetic waves.

The history of electronics from the first electron tube was largely the story of the struggle by scientists and engineers to generate and amplify higher and higher radio frequencies. The problem of working with shorter waves of the higher frequencies necessitated ever-smaller dimensions in oscillators so as to be resonant with — or tuned to — the ever shorter waves.

It seemed that ultimately the problem of making such small tubes and transistors would limit the expansion of communications to the higher frequencies. Thus after pushing into the microwave regions, scientists were limited in obtaining higher frequencies because of the extremely short wavelengths involved. Why not let atoms and molecules serve as their own resonators? This was the question being pondered by

Atoms Viewed From a Park Bench

some scientists in the early 1950's. Among them was physicist Charles H. Townes. He wanted to have a better understanding of the reasons specific materials absorb and emit particular radio frequencies and colors of light. He had become interested in this field — spectroscopy — while working at Bell Labs during World War II. He continued this research as a professor at Columbia University.

Townes felt that work in spectroscopy was hampered by lack of sources of pure, high frequencies. He and other scientists, who for various reasons had been exploring the high frequency problem, were to meet in Washington, D.C., on April 26, 1951.

The night before the meeting, Townes stayed in a small Washington hotel. When he awoke at 5:30 a.m. his mind kept mulling over the high frequency problem. He dressed and left the room.

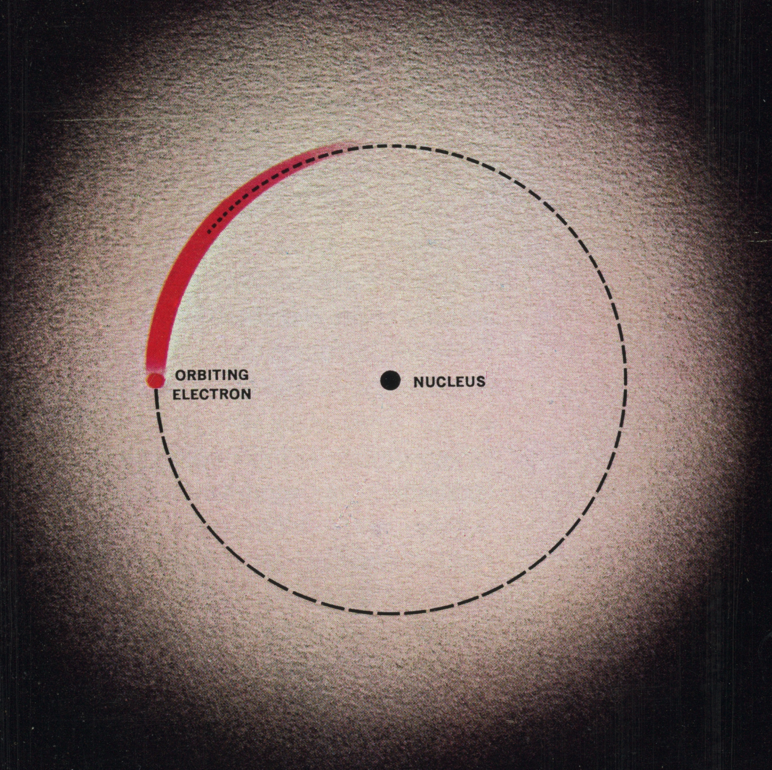
Downtown restaurants were not yet open. He took a walk in the mild April dawn. As he walked, he pondered. He sat on a park bench in the early quiet, savoring the spectacle of azaleas in bloom. His thoughts ran over pieces of theory and information about the world of atoms, which had been known to scientists for 30 years.

No one, of course, has really seen an atom. Yet, not unlike a blind man tapping his way down familiar streets and even through busy traffic, scientists have formed a picture of the atomic world. Using theory, experiment, inference and mathematical analysis, they continue to learn more detail.

The arrangement of electrons around the nucleus of an atom is somewhat analogous to our solar system, with the nucleus as the sun and the electrons as the planets. The atom's orbiting electrons constitute a wonderfully versatile mechanism for absorbing, storing and emitting energy. You can wind up each individual atom like the rubber band of a model airplane. You pump in energy to wind the atom up and, as it relaxes, it radiates energy — in the form of waves.

Atomic emission of radiation is commonplace. This is exactly what happens in an electric light bulb. You wind up the atoms in the tungsten filament by heating them with an electric current. The tungsten atoms become violently excited and collide with one another, and many of them absorb additional energy from the atoms they bump into. This means that the excited atoms and their orbiting electrons have even more energy than "normal."

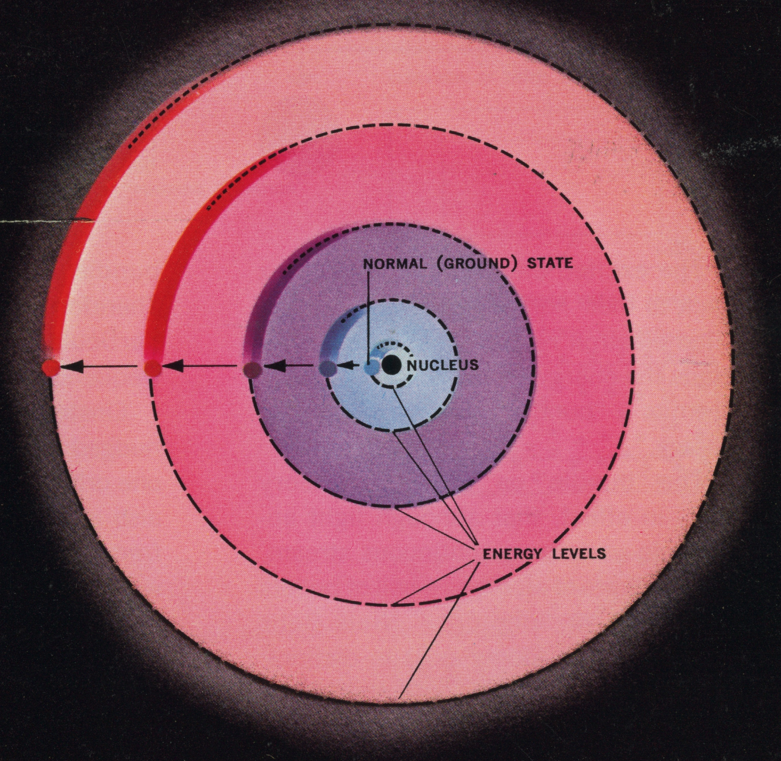
An atom may be considered a tiny particle of matter with a center of mass called a nucleus surrounded by one or more electrons orbiting around the nucleus. The simplest atom, hydrogen, has one electron orbiting its nucleus. The electron shown here is not in its normal state, but is in an outer orbit (energy level).



ACTUAL SIZE: 1 ANGSTROM UNIT ($\frac{1}{100,000,000}$ CENTIMETER)

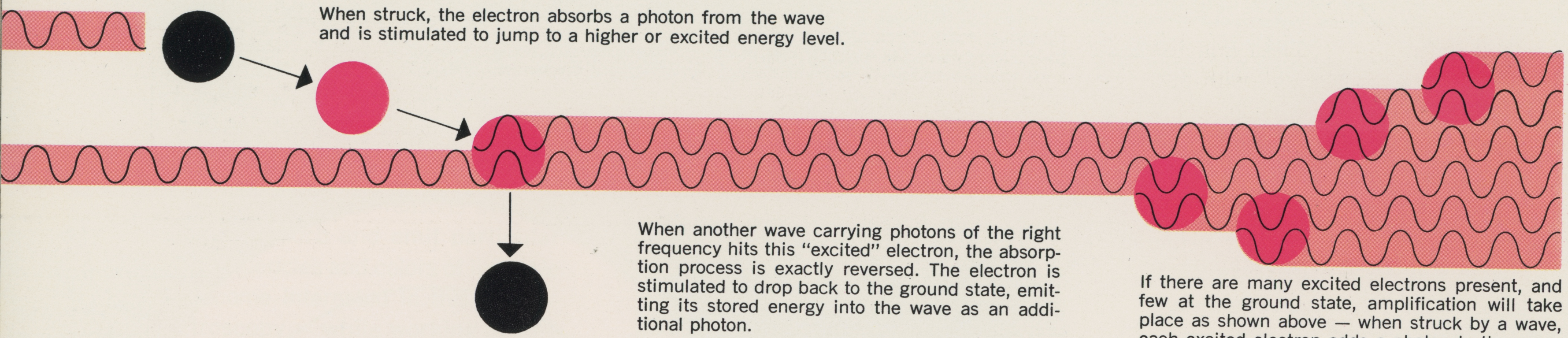
HYDROGEN ATOM

With the proper stimulation the electron in an atom goes from its innermost orbit (energy level), or normal state, to any of several outer orbits. When the electron returns to a lower orbit it emits small packets of light energy called photons. The ability of atoms to radiate energy at a specific frequency is one key to laser function.



ENERGY LEVELS OF THE ELECTRON IN A HYDROGEN ATOM

STIMULATION OF AN ELECTRON BY AN ELECTROMAGNETIC WAVE (PHOTON)



An electron at the lowest energy level (ground state) about to be hit by an electromagnetic wave carrying bundles of energy (photons) of a specific frequency.

When struck, the electron absorbs a photon from the wave and is stimulated to jump to a higher or excited energy level.

When another wave carrying photons of the right frequency hits this "excited" electron, the absorption process is exactly reversed. The electron is stimulated to drop back to the ground state, emitting its stored energy into the wave as an additional photon.

If there are many excited electrons present, and few at the ground state, amplification will take place as shown above — when struck by a wave, each excited electron adds a photon to the wave.

The excited electrons tend to relax back to their normal state. As each excited electron relaxes, it spontaneously emits the energy it previously absorbed. It emits a "bundle" of electromagnetic energy.

The "bundle" or "quantum" theory says, in effect, that although light appears to *us* to be a continuous stream, light appears to *atoms* as a hail of bullets of energy, or "photons." Niels Bohr suggested that atoms exist in distinct, separate energy levels and that when they go from one level to another they either emit or absorb these bundles of energy.

Albert Einstein proved by analysis in 1917 that electrons can be stimulated to jump up or drop down from one energy level to another by a photon, or bundle of energy, of just the right amount. The amount of energy in each bundle depends upon its frequency. Therefore the change of energy in any particular atom is related to specific frequencies of electromagnetic energy.

Einstein added that when a photon nudged an electron into dropping from one orbit to another, the electron would also emit another photon of the *same frequency* as the one that hit it; and it would emit that photon in the *same direction*—so that the emitted photon's energy would be added to the photon that stimulated the action. Here, potentially, was amplification.

All these concepts had been known for years and had been further advanced. The problem was to find a way to control the phenomena in order to amplify and generate high frequencies.

Sitting on the park bench, Townes suddenly put the pieces together differently — and hit on the first glimmering of a new, concrete way to produce and amplify short electromagnetic waves!

He would upset the natural state of equilibrium in atoms, or molecules, to create a situation with an abnormally large number of high energy electrons. (Scientists had already explored some ways to do this.) Then he would use the right electromagnetic frequency to stimulate the electrons into emitting their stored energy. This would produce electromagnetic waves. (See diagram this page.) He would feed these waves back into the material to stimulate other electrons. Then the action would cascade into a powerful wave. He saw that this "feedback" could be accomplished by carrying out the process in a cavity resonant to the wavelength.

In a few minutes he had figured out on the back of an envelope some of the most important requirements.

Atoms at Work

Back at Columbia, Townes and his students began working with ammonia. Its microwave emission, being well understood, seemed a good material to try first. They beamed excited ammonia molecules into a metal box resonant to the right microwave frequency, and shone microwaves on the excited ammonia. In 1953, after many experiments, they finally succeeded. The box emitted a pure, strong beam of microwaves, far more exact in frequency than anything achieved before!

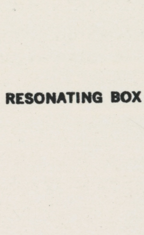
They called the device a M-A-S-E-R, standing for Microwave (or Molecular) Amplification by Stimulated Emission of Radiation.

But ammonia worked at only one frequency. Scientists began casting about for materials they could "tune" with a magnetic field. Nicholaas Bloembergen of Harvard proposed a *three*-level maser using a magnetic crystal. Scientists at Bell Laboratories designed and built one, and soon they got the first solid-state maser to work.

In this model, a "pumping" frequency excited the electrons to a level two levels higher than "ground." The electrons fell quickly to the second level and lingered there until "triggered" by the right frequency before falling to the ground again, thus *amplifying* the trigger frequency.

THE THREE-LEVEL MASER

Normally, most atoms of a material have electrons at the lowest energy level (ground state). To function as a MASER (or LASER) the electrons must be "pumped" to a higher energy level and enclosed in a resonant box "tuned" to just the right frequency.



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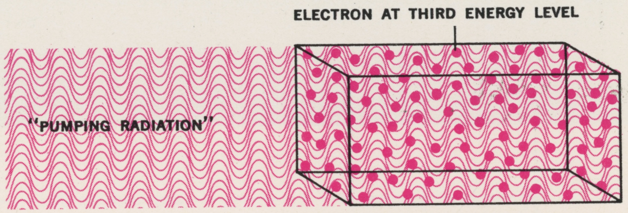
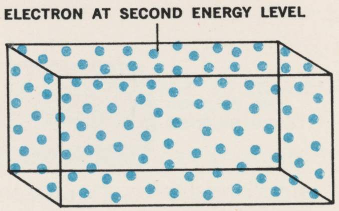
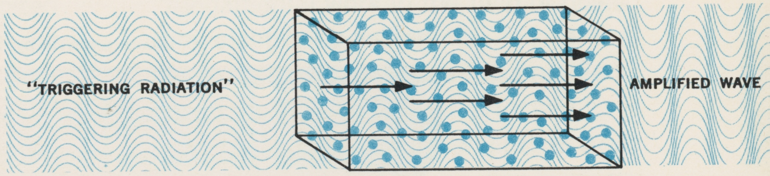
1 Using a crystal to provide the atoms required, a "pumping" radiation is introduced to raise most of the electrons to the higher energy levels.



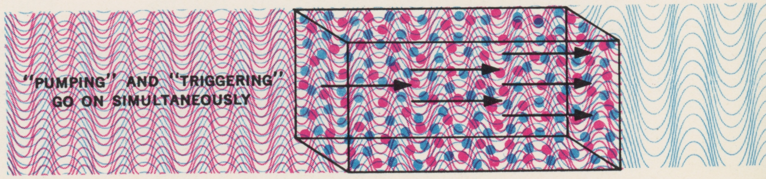
2 The excited electrons fall spontaneously to the second energy level (and linger there for a split second).



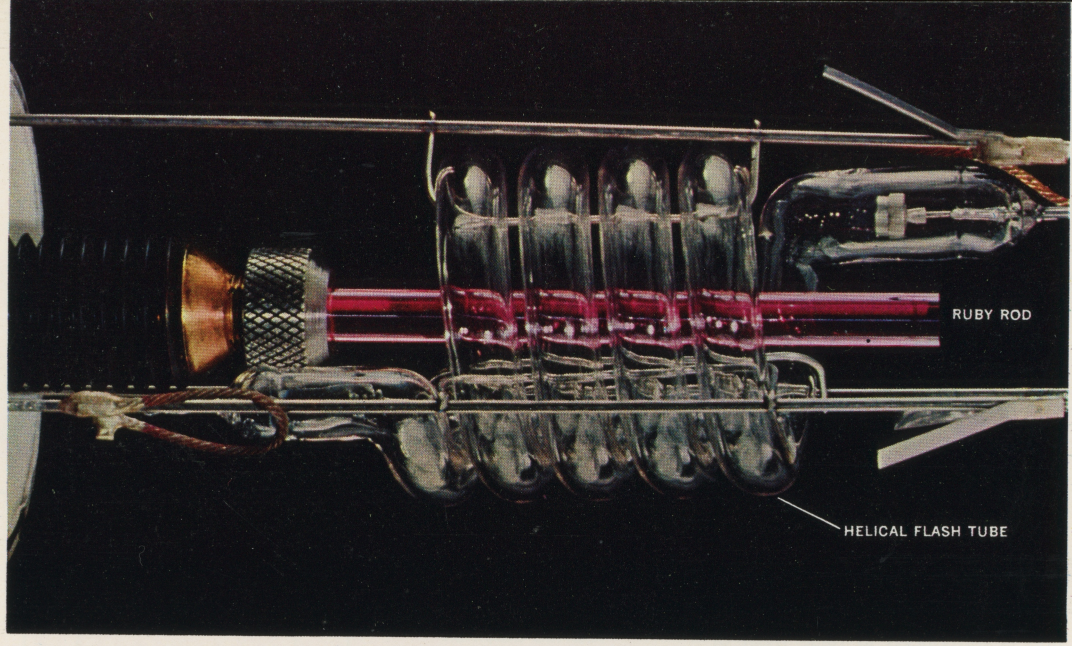
3 A "triggering" radiation of the correct frequency is introduced, stimulating the electrons to radiate their stored energy. In this way MASER type amplification takes place in the resonating box.

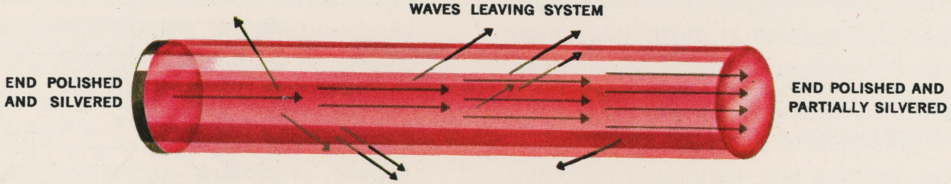


Since the "pumping" radiation is absorbed by ground state electrons, and the "triggering" frequency stimulates second level electrons only, the operations can go on simultaneously. As electrons fall back to ground state they are "pumped" up again, and MASER action is continuous.

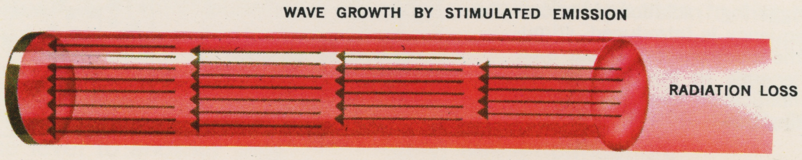


THE PHOTON (WAVE) CASCADE IN THE RUBY LASER

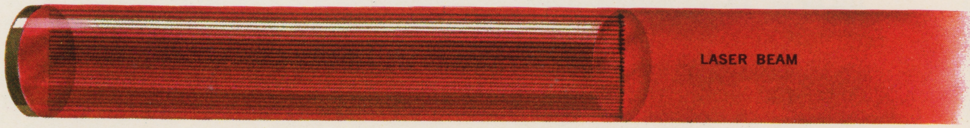

RUBY ROD
HELICAL FLASH TUBE


WAVES LEAVING SYSTEM
END POLISHED AND SILVERED
END POLISHED AND PARTIALLY SILVERED

The ends of a ruby rod are flattened (so they are parallel), and silvered to form mirrors. The mirror at one end is made to reflect only part of the light so that when there is a buildup in energy between the mirrors, the beam can escape.


WAVE GROWTH BY STIMULATED EMISSION
RADIATION LOSS

Soon after the chromium atoms in the ruby crystal are pumped by a flash lamp to a higher energy level, they drop to another level and stimulated emission takes place. Waves moving at angles to the crystal's axis leave the system, but those travelling along the axis grow by stimulated emission of photons.



The parallel waves are reflected back and forth between the mirrors and the wave system grows in intensity. A pale red glow indicates a certain amount of light being lost at the mirror, but beyond a critical point, the waves intensify enough to overcome this loss and an intense red beam flashes out of the crystal's partially silvered end.

The three-level maser is the world's most sensitive radio amplifier. Because it generates virtually no radio noise of its own, it can amplify the merest radio whispers. Soon Bell Labs had developed a type of maser, using man-made ruby, that would amplify a broad range of frequencies. These ruby masers were later to be used to amplify weak signals from the Echo and Telstar® satellites. Astronomers use them to amplify radio energy emitted by distant stars.

Still, these devices worked only at microwave frequencies and scientists had not yet found a way to generate pure light frequencies. In 1958 Townes and Arthur L. Schawlow of Bell Labs proposed a light maser (or laser) with a column or rod of material between two polished plates. The first, built by Theodore H. Maiman of Hughes Aircraft Co. in 1960, used an intense flash of light to "pump" a ruby rod, silvered at the ends. Light waves went back and forth between the mirrors to cascade the action. The light emerged from this type of laser in a short, powerful burst. It was coherent light.

Short bursts of light are not of much use for communication. Eventually Bell Labs succeeded in making the ruby lase continuously. But in the meantime, Ali Javan had conceived his idea of a tube containing a mixture of two gases that by their nature would lase continuously.

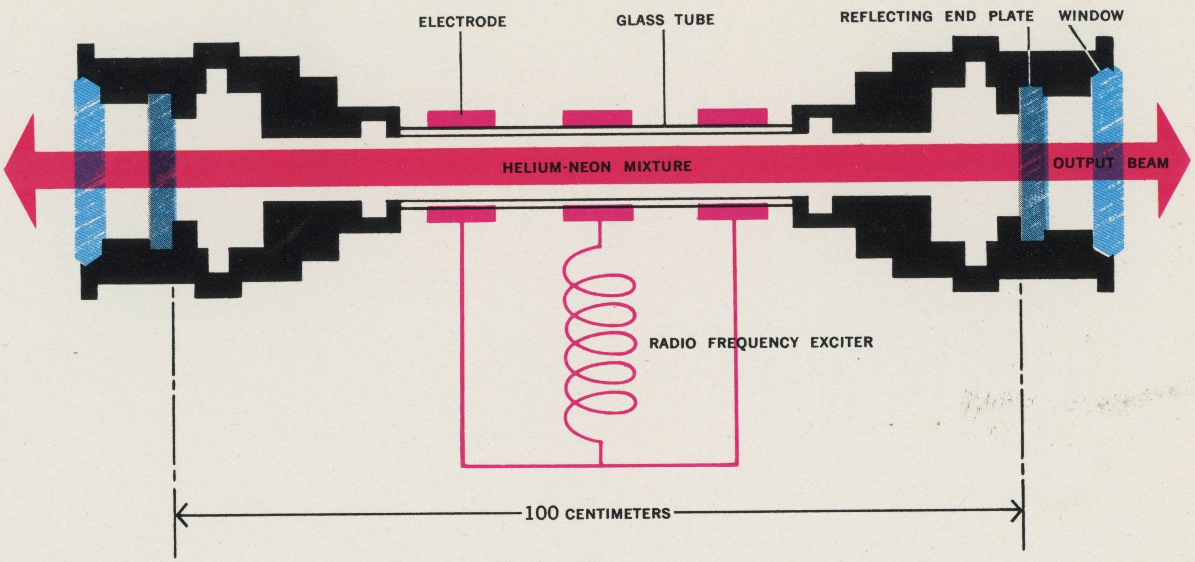
The combination of gases was so chosen that certain energy-level characteristics of each gas were nearly the same. The first combination tried was helium-neon. A little electrical energy would agitate the helium atoms. They would collide with the neon atoms, transferring some energy to the neon atoms and raising them to an excited energy level. A light wave would get started, race back and forth, trigger more atoms, and emit an invisible infrared light — coherently and *continuously.* After a lot of patient study and effort, as we have seen, that is exactly what happened.

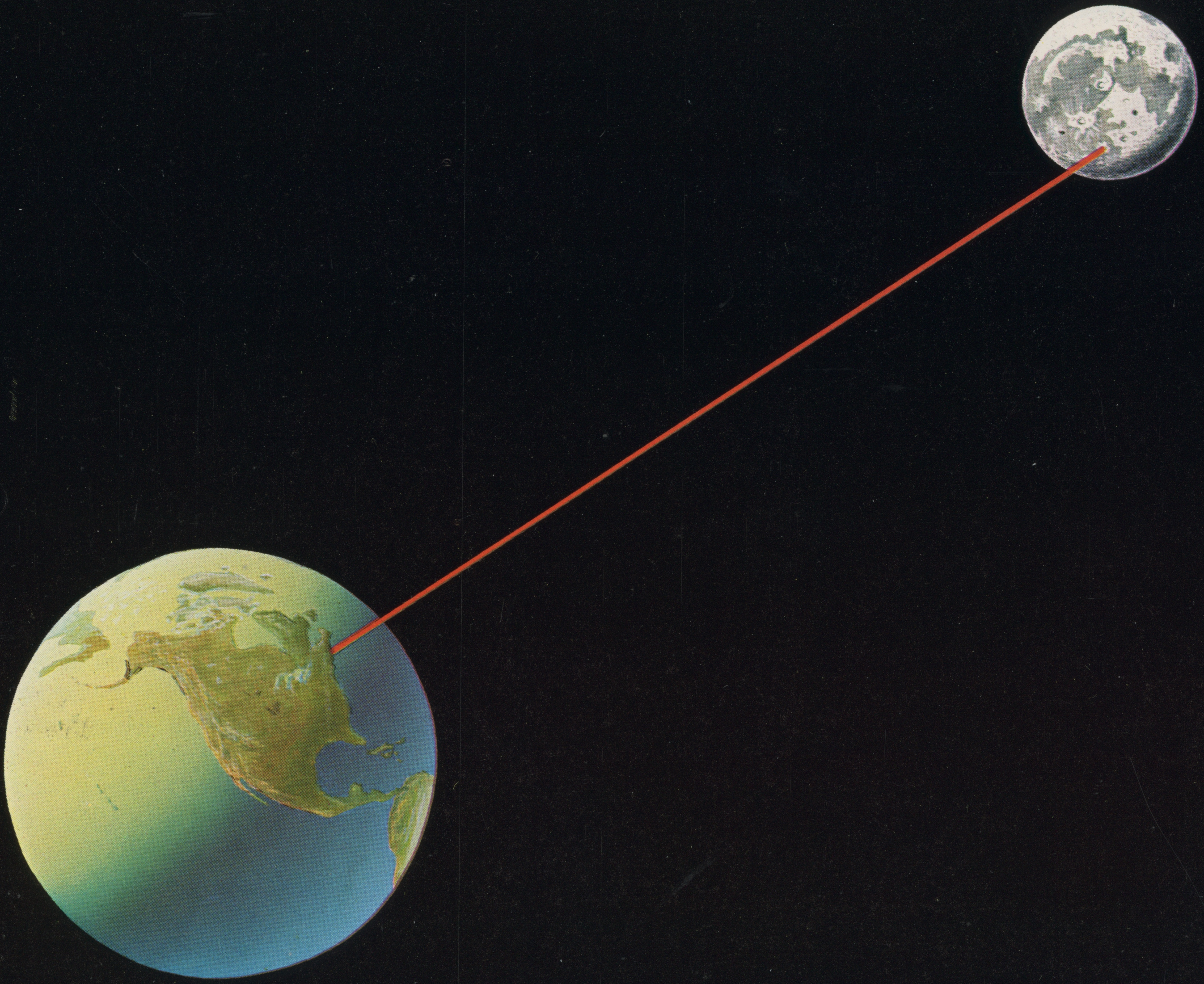
Thus Townes' idea in that first light of morning in 1951 led eventually to the dawning of another kind of light!

In 1964, Townes — then Provost of the Massachusetts Institute of Technology — was awarded the Nobel Prize in physics. Also awarded the prize were Alexander M. Prokhorov and Nikolai G. Basov, both of the Lebedev Institute in Moscow, whose work paralleled some of Townes'. The prize was awarded for "fundamental work in the field of quantum electronics which has led to the construction of oscillators and amplifiers based on the maser-laser principle."

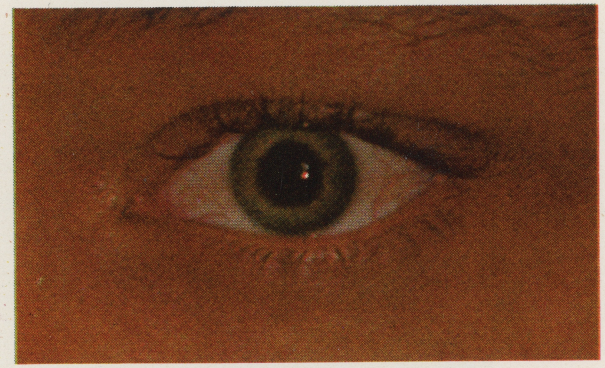
In rapid succession, scientists and engineers produced laser action in many other combinations of gases, even in liquids, plastic and glass, and in tiny, almost microscopic semiconductors of solid material. Laser frequencies have been extended into the ultraviolet region and down into the lower infrared to meet maser frequencies thrusting upward from the microwave regions.

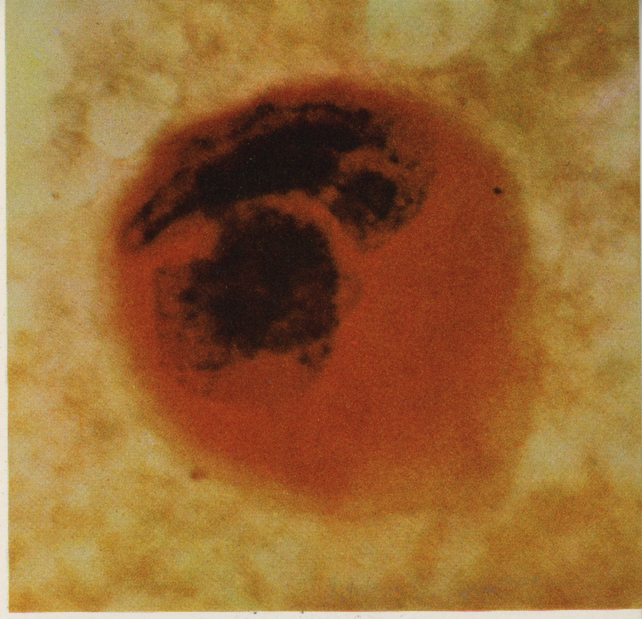
THE HELIUM-NEON LASER





A laser beam has been bounced off the moon and back to earth.





The Laser's Potential In Many Fields

Scientists already view the laser as an important laboratory tool. They feel that its specific commercial uses will stay mostly in the background until more fundamental knowledge is acquired. The laser is such a new device, designed on such radically new principles, that scientists and engineers have to catch up, in a sense, with their own remarkable achievements.

The laser is useful in the laboratory because it produces light energy of unprecedented intensity and purity and is readily focused. A laser can concentrate a beam of extraordinary intensity in a small spot — specifically, about the diameter of a human hair. Furthermore, it can be sent backward through a microscope and focused, for example, on the smallest portion of a biological cell that can be seen on the microscope. It could be used in surgery to eliminate a single infected cell.

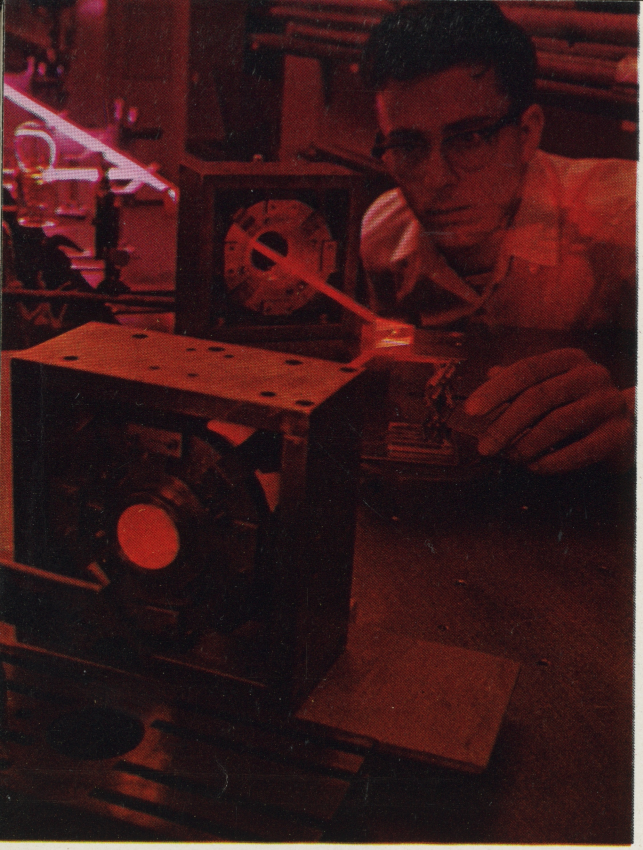
The laser has made feasible a new kind of lensless photography — holography — which needs coherent light to "capture" light waves in a photographic plate. The plates — called holograms — can be used, among other things, to produce truly three-dimensional pictures.

Scientists have triggered chemical action in a small group of molecules in a compound. They are using the laser to explore the molecular structure and internal behavior of materials.

They could use its intense light — thousands of times brighter than sunlight — to photograph extremely fast-moving objects, capture a picture of materials the instant they fracture, melt or explode.

Because it is so pure, laser light can be used to measure that great universal constant, the velocity of light, more accurately than ever before. Scientists at the Massachusetts Institute of Technology have carried out a laser experiment under the vibration-free conditions of a wine cellar on Cape Cod to determine whether the velocity of light changes with the velocity of the observer. Light travels at 186,000 miles per second. With a laser, the experimenters detected no change.

Some lasers are very powerful. The power of continuous gas lasers is measured in a few hundred watts. But fantastic momentary bursts of power are achieved in lasers that use crystals such as the ruby. The power of a pulse can be 100 million watts. But this power is not continuous. It lasts only a fraction of a



A Bell Laboratories technician adjusts a prism to bend a laser beam onto a reflecting mirror.

second, like a pistol shot. Then, the power supply takes a comparatively long rest before the next pulse. To produce 100 million watts continuously would require a power supply equal to that of at least 10 cities.

The high power characteristics of a beam of laser light may open a whole new range of experiments and studies in the field of high temperature physics. Lasers that emit short pulses of extremely intense light have already been focused on a carbon block to generate temperatures up to 10,000 degrees Fahrenheit. These lasers could be used to test materials, such as ceramics and alloys, that may have to withstand intense heat.

What about potential "practical" uses? Because its frequency is so high, laser light may be used in a radar to distinguish the nature of distant objects in far greater detail than can the longer waves in the microwave range.

High-powered lasers may be used to cut and weld precisely, and reach places otherwise inaccessible. Western Electric, manufacturing arm of the Bell System, has developed a method of drilling holes in diamond dies using laser light.

Lasers could become a great boon to our space work. In empty space, where there is nothing to absorb light, a laser could be seen by the naked eye as far as one tenth of a light year. It could be used for signaling and for measuring very accurately the velocity of satellites. Lasers have already been used to track objects in outer space.

Because of its great directionality — its extremely narrow beam — laser light could be used for a variety of previously impossible surveying tasks, like mapping the moon. A satellite-mounted laser could also be useful in charting coastlines and inaccessible mountain ranges; or possibly, for determining the size and speed of cloud formations for assistance in weather forecasting.

Right: micro-machining and welding with the laser are among many jobs possible with the new tool.

The Outlook for Lasers In Communications

Within 24 hours after Bell Labs scientists operated the first continuous laser, it carried a single telephone voice. This was the beginning. While a cross-country microwave system can now carry up to 16,800 voices, a laser beam has the theoretical capacity to carry hundreds of millions — or *all* the telephone, data and TV traffic now being handled by every radio system in the world.

Why then isn't it being done? An old saw applies to the situation: "If we had an egg, we could have eggs and bacon, if we had some bacon and a frying pan, a match and a fire." So far we have only the egg, although we are making progress on the others. We are learning much more about how to impress a very broad signal on a laser beam, send it some distance despite fog, dust and precipitation, detect it, and then filter the voice signals off at each terminal. And as yet there is no use for it that would pay off, though this is developing with time. The increasing need to have computers communicate with each other is an example.

Besides the question of need, there is the question of how well a laser system will compare in cost with other available systems. Coaxial cable and microwave systems are not only meeting today's needs but continually are being reduced in cost and improved in reliability and longevity. A large capacity laser system then must compete with many smaller-capacity but well-developed conventional systems.

Dr. James B. Fisk, president of Bell Laboratories, has summed it up: "We don't know when all the precision controls essential for laser communications can be achieved. But we expect to learn how and at what cost in the next few years — before the need is with us."

The bright red glow in the distance is laser light. The beam is being studied to determine the effect of atmospheric conditions upon it.

In Short Masers and lasers are a new class of electromagnetic generators and amplifiers, operating in the microwave and light portions of the spectrum. Scientists, foreseeing a need for higher frequencies, had purposely set out to obtain them. Working from theory, they devised ways to manipulate energy and matter on the atomic level, and produced a scientific achievement of the first order.

Some masers are used as sources of pure, precise frequencies, while others, the world's most sensitive microwave amplifiers, are used in satellite communications and radio astronomy.

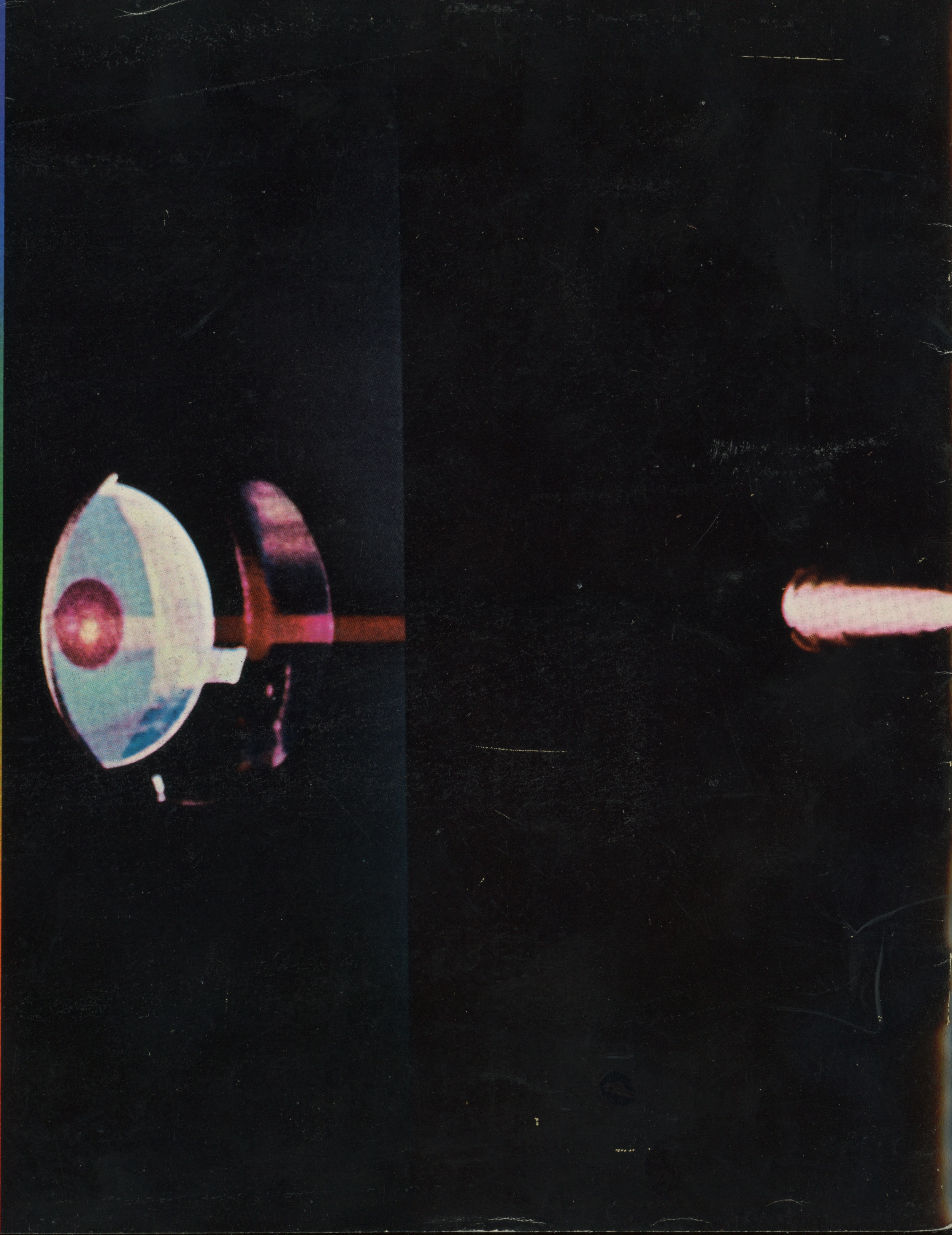
The laser has produced coherent light for the first time. This light, with its unique qualities, appears to have many practical uses. It offers a vast but as yet unfulfilled promise as a carrier of bulk communications.

Bell Laboratories has played a leading part in the scientific development of masers and lasers, and has actively explored their possible application to communications.

In research laboratories the laser will unquestionably be used to increase our understanding of the natural world we live in. It will help provide fundamental information to some future scientist who, perhaps seated on a park bench, will suddenly grasp a new idea.

The laser — like all genuine advances in science, or in art, or in medicine — will affect our lives and the way we live whether we are aware of it or not.

BELL SYSTEM



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